# §1. Operational Status of Negative-Ion-Based Neutral Beam Injection System in LHD

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The negative-ion-based neutral beam injection (NBI) system in LHD has progressed in its performance year by year. In the present LHD plasma experiments, the NBI is the most reliable and the most powerful heating method. The NBI system consists of three tangential injectors, BL1, BL2 and BL3, and various modifications and their tests of ion sources are carried out every year to improve the performance. These modifications and tests in the 8th LHD experimental campaign are reported, including the injection summary in the plasma experiments. Figures 1 and 2 show an injection history in the 8th LHD experimental campaign for the total port-through injection power and the individual injection powers of three injectors, respectively.

BL1 achieved a high power injection of 5.7MW in the previous campaign. The modified ion sources equipped with multi-slotted grounded grid enabled this high-power injection. However, there is a problem of large vertical beam divergence and different operational conditions for the vertical and horizontal beam steering, which cause excess heat load on the injection port. To solve this problem, a round aperture shape of the steering grid, which is used for the beamlet steering by the aperture displacement technique, was modified to a race-track shape, and the operational test was carried out. The results show mitigation of anisotropical properties of the vertical and the horizontal steering conditions. This modification will be applied to the BL1 ion sources in the next campaign.

In BL3, the outputs of the arc and filament power supplies are divided into twelve circuits, and the individual arc and filament voltages were simultaneously controlled so as the arc power distribution was made uniform. As a result, the beam uniformity was improved, leading to enhancement of the injection efficiency. The injection power was also increased to 4MW, as shown in Fig. 2.

The injection duration has been extended over several tens seconds in the long-pulse experiments. However, the further extension is restricted by an excessive rise of the plasma grid (PG) temperature, which should be maintained at 200-300$^{o}$C for efficient negative ion production in the cesium operation. To suppress the PG temperature rise in the long-pulse injection, stainless-steel cooling tubes have been mechanically attached on the PG in BL2. As a result, the injection duration was extended to above 120sec with an injection power of 0.2-0.3MW using one ion source. On the other hand, the pri-arc duration must be extended to above 15sec to maintain the appropriate PG temperature in the short pulse injection. This nearly doubled arc discharge duration led to reduction of the filament lifetime and enhancement of the Cs consumption. Since the operational conditions were not optimized in the short pulse injection, the injection efficiency was lowered and the injection power was no more than 3MW in BL2.

The total injection power was 11.3MW at maximum in the 8th campaign, which was a little less than that of 13.1MW in the previous campaign. In BL1, there happened water leak at the flexible tube for cooling the grounded grid due to mechanical fatigue. The injection power of BL2 was reduced with the cooled PG in the short pulse operation. These caused the reduction of the total injection power.

The new grid system in BL1 is expected to increase the injection power, and by using the uncooled PG for the short pulse injection the injection power will be recovered in BL2. Therefore, the total injection power is expected to be increased in the next campaign.

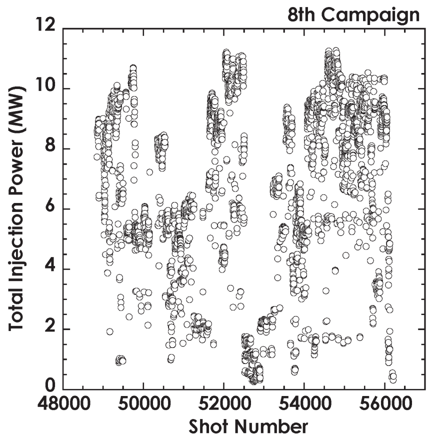


Fig. 1. History of the total injection power in the 8th experimental campaign.

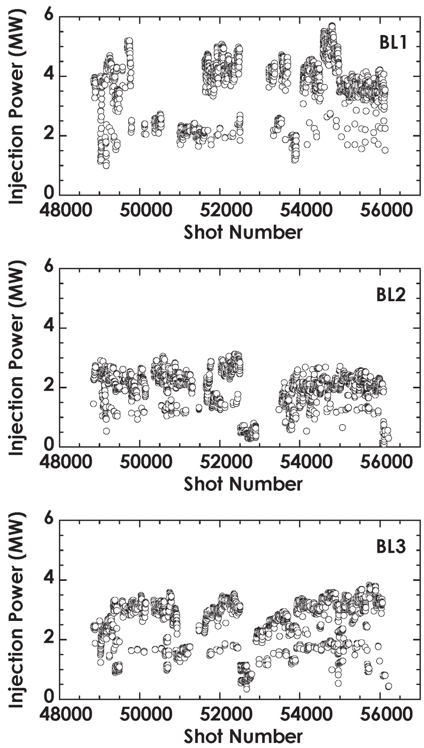


Fig. 2. History of the injection power of the individual injectors of BL1, BL2, and BL3.